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Fireline Production: A Conceptual Model

Richard J. Barney

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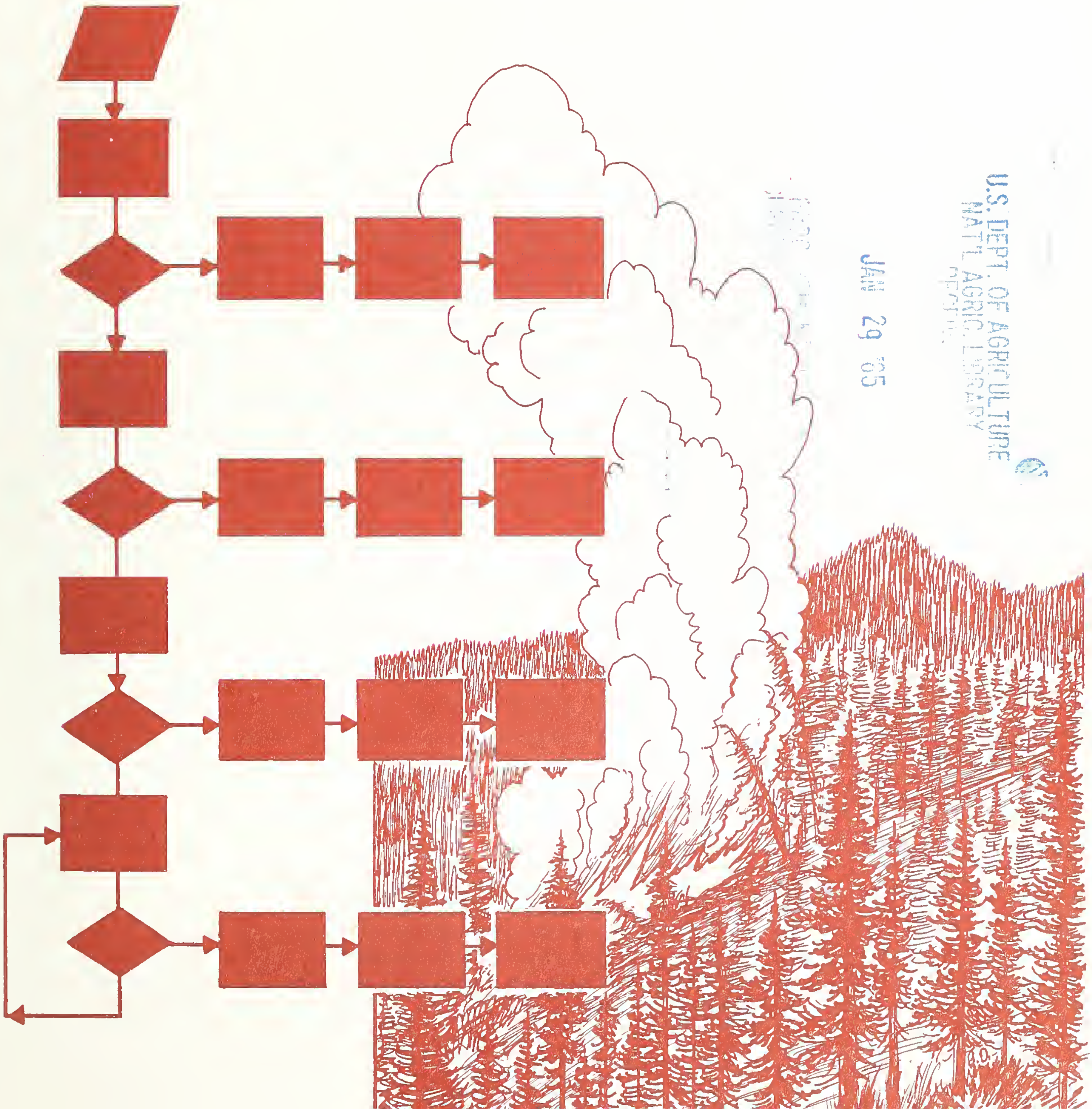

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RICHARD J. BARNEY received his bachelor's degree in forestry in 1958 and his master's degree, also in forestry, in 1961, both from the University of Montana. His Ph.D. was received in 1976 in forestry from Michigan State University. From 1958 to 1961 he worked on the Flathead National Forest. From 1961 to 1965 he was located at the Northern Forest Fire Laboratory, involved in fire behavior and fire danger rating research. In 1965 he transferred to Fairbanks, Alaska, where he was project leader of the Alaska Fire Control Systems Research Unit. Following this assignment, he returned to the Northern Forest Fire Laboratory, where he is currently a team leader in the Fire Control Technology project.

RESEARCH SUMMARY

This report describes a conceptual model that provides a framework for the components of fireline production. Other conceptual or operational fire-related models may be linked with this production model. Major components and relationships are diagramed.

Fireline production is a component of the broader fire suppression process. The production of fireline has been defined by four phases: management phase, theoretical phase, application phase, and evaluation phase. The model provides a basis for standardizing components, which helps insure future compatibility. This conceptual approach enables managers to tailor production outputs to a specific site and situation. Application of the model should improve planning and fire management.

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INTRODUCTION

Fire suppression capabilities and rates of production have long been of interest to firefighters and fire managers. The need for and use of fireline production information has been well documented in agency manuals and planning procedures. Fireline production information answers questions like the following:

1. What are the production rates and capabilities of crews and mechanical equipment for producing effective fireline under various environmental and site conditions?
2. How many firefighters or how much equipment is needed to contain or suppress a specific fire?
3. How wide must the fireline be to hold?
4. How does the width of fireline vary with changes in fuel, weather, and other site factors?
5. What are the optimum combinations of people and equipment such as tools, dozers, and tankers to develop the best production rate?
6. How do we obtain production rates for combinations of line-building methods?

Such information is necessary to determine the personnel and equipment required to accomplish a given job, and to obtain the most return for each dollar spent on fire suppression efforts. Cost information, including resource costs on fires, by its very nature, is linked heavily to production information.

Historically, fireline production information has considered only a limited number of input variables. Essentially, production rates considered only crew size, training, or experience level and a broad fuel classification. Fuel classification was further broken down into rate-of-spread and resistance-to-control categories. Resistance to control provided a measure of how much fuel had to be removed and often reflected the amount of crosscut saw work that was necessary, or some other measure of line construction difficulty. Each regional set of resistance-to-control guides was developed based on individual experience, rather than from an in-depth objective study. Such experience-based information was and still is a very important source of data. The classification schemes often used relative values ranging from a "low" to an "extreme" category. Sometimes a term like "medium" was defined, but usually not in quantitative terms.

The same general scheme was used to rate and classify fire rate of spread. The subjective rating usually ranged from low to extreme. Again, categories were ill-defined in quantitative terms. The most popular method to rate fuels was through pictures or narrative descriptions. When a different fuel type was encountered, it would be given a rating such as H-M (high rate-of-spread potential—medium resistance to control). Most of the production information has been expressed in these types of terms, even in some of the more recent studies.

PAST AND CURRENT WORK

Fireline production information has been gathered since the turn of the century. In the mid–1930's, a considerable amount of information was developed. This may have been partly due to the formal beginning of fire research, as well as the need for better data to support "new" Forest Service policies. Hornby (1936) listed the most important factors that influenced rate of construction of fireline per man-hour:

1. Fuel resistance to control
2. Method of attack
3. Kinds of tools, equipment, and food provided
4. Efficiency of directing officers
5. Training and experience of firefighters
6. Physical and mental abilities of firefighters
7. Size of crew
8. Size of fire
9. Aggressiveness and heat of fire
10. Prevailing atmospheric temperature
11. Fatigue
12. Darkness

These items seem appropriate today, with some slight modification of terms to fit current systems of operation and available research data. Work of Abell (1937), Buck (1938), and Hanson (1941) provides additional regional input to the fireline production rate data bases. In 1969, Storey summarized existing productivity and line-building data. He felt there were adequate hand-crew data available, but quality was questionable. Bulldozer data were found to be in a similar condition. He felt one shortcoming of the production data was that they lacked good information on fire behavior. In addition, the data lacked applicability on a broader geographic basis. He felt a national system for rating fuels for fire rate of spread and resistance to control was urgently needed.

In addition to Storey's summary work, several efforts have been made regarding fireline production. These efforts range from the theoretical efforts of McMasters (1963) to hand-crew studies of the California Department of Forestry (Weaver 1976). Some of the complaints with earlier studies—inadequate ties to conditional and site variables—are also appropriate for these efforts. Barney and Noste (1973) attempted to tie both crew and machine production efforts to conditional and site parameters in Alaska, but data collected were limited. In the early 1970's, Lindquist (1970) developed crew production data, but, again, this work was not tied to environmental, site, or other factors. Production rates for various line widths were determined, however. In the middle and late 70's, the USDA Forest Service Equipment Development Center, Missoula, Mont. (Ramberg 1974), carried out fireline production studies in conjunction with their firefighter fitness and physiological research. Although they found the same kind of wide variation

in older study data, they concluded that fireline production rates in current guides are too high—50 to 100 percent—in most cases. Murphy and Quintilio (1978) developed crew production rates that included some details for fuels and construction resistance. The most recent efforts in attempting to make sense out of production information are by Haven and others (1983). Although these efforts are not yet completed, they essentially update the earlier work of Storey.

OBJECTIVE

The high value of resources today, laws, policies, and the vast array of more sophisticated and expensive equipment dictate against use of simplistic systems and limited data bases. Suppression capabilities relative to production need to be expressed in terms that go beyond simply the time required to build a fireline from point "A" to point "B". Management decisionmakers need more detailed information and more precise tools. Suppression capabilities need to be expressed in terms that lend themselves to more sophisticated analysis and application. Recent developments in fire models, fire danger ratings, and economic evaluation procedures all require more improved information. Links should be developed among various suppression capabilities, fire characteristics including site and behavior factors, and situation parameters such as management objectives, economic criteria, and impact assessment. Research outputs must also be compatible with operating and planned data synthesis and analysis techniques.

This paper is an attempt to define the process of fireline production. A conceptual model is presented and discussed in an attempt to overcome problems found in earlier production data. By providing a more detailed view of the system, it is hoped the appropriate data can be provided in such a manner as to become more universally understood and useful. A model such as presented here provides a logical basis for linking segments of the fire management system.

FIRE SUPPRESSION SYSTEM

A general model of the fire suppression system is shown in figure 1. The process begins with the detection or discovery of an actual wildfire through either traditional detection and reporting processes or by a simulation of a fire-start in a gaming process. The first attack follows detection, assuming action is to be taken. The goal of the first or initial attack is to contain the fire, suppress it, and mop it up until it is declared out. There are two possible outcomes—success or failure. If sufficient force is promptly dispatched to the fire, reaches it, and takes sufficient action, the fire will be contained and, eventually, put out.

During initial attack, fireline production is different in many respects from later reinforcement and sustained production. In initial attack, the most active areas are usually hit first, then the less active or nonactive areas. The fire is "hot-spotted," or cooled down, then ringed with some form of line. The basic approach is to contain the fire at a rate faster than the fire is spreading, so as to surround and eventually control the fire. If the suppression force is successful during its initial attack phase, the fire is contained, mopped up, and completely extinguished. If, on the other hand, first efforts are not sufficient to accomplish the goal, reinforcements or additional time, or both (wait for evening, fuel change, etc.) will be necessary. Fire behavior is predicted and enough additional personnel and

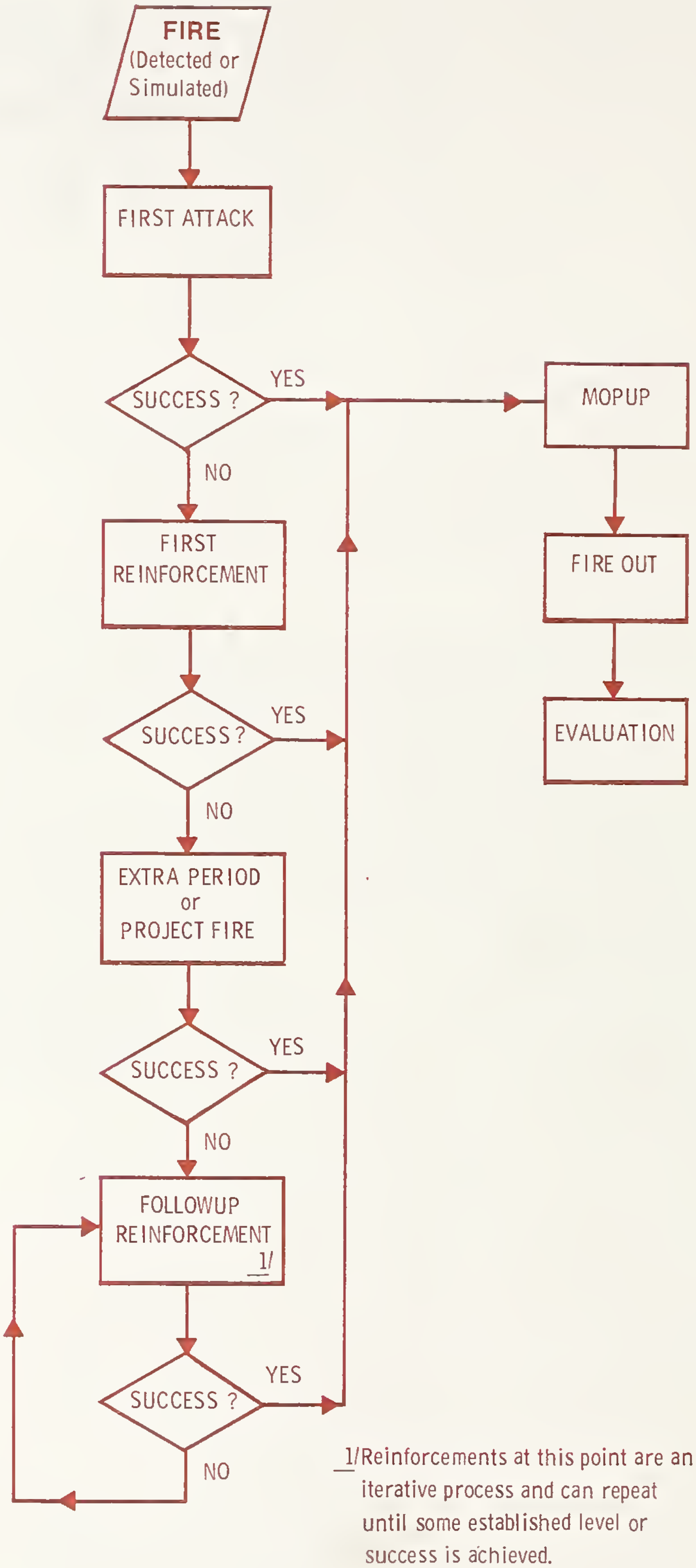

Figure 1.—A simplified model of fire suppression efforts.

machinery are dispatched to retard the fire growth at a rate faster than the spread of the fire. Disregarding other variables such as weather, fuel, and site conditions, the larger the fire, the more total work effort is required and the more difficult the task becomes to contain it. If sufficient effort is provided with the first reinforcements, success will follow. If this level of effort is not adequate, failure will occur. The type of production usually found in first reinforcements is often similar to the "hot-spotting" found in initial attack. However, with greater suppression resources, the tendency is toward more methodical effort.

When first reinforcements fail, there is a chance that the fire is or will become an escaped fire and possibly a project-size fire. When this happens, the situation must be reevaluated, additional forces added, or effort of existing forces continued under different environmental conditions. The general goal is still to build fireline at a rate faster than the fire perimeter is increasing. Modified use of this concept, such as herding the fire through judicious use of fireline into an area of flat ground, light fuels, rivers, lakes, etc., is also practiced. Depending on the success of subsequent events, followup may be made and continued until reinforcements are either no longer available, economically inaccessible, or not needed.

As a general rule, the type of production in fire suppression moves from a quick assault action to a slower, more methodical construction procedure. It is, therefore, worth considering two and possibly more levels of fireline production rates by virtue of intent alone. Followup reinforcement can be an iterative process until success or some other cutoff level is reached.

FIRELINE DEFINITION

Fireline, by definition, is a manmade or natural barrier that impedes the progress of a fire traveling through ground fuels. More specifically, it has been defined as "that portion of a control line from which flammable materials have been removed by scraping or digging to the mineral soil." It is the author's contention, however, that when developing production information, there are two categories of fireline: (1) fireline constructed to bare mineral soil, and (2) fireline classed as "other." This latter category includes all processes and activities that produce a fire-stopping barrier without removing materials to mineral soil. Examples are areas wet down with water. Retardant could fall into this second classification if the fire's progress was stopped, not just retarded. Burned-out strips, "black line" established without the aid of water or retardant, or a beaten line such as created by flappers or sacks could also fall into this "other" fireline.

For the purpose of this paper, eight categories or components of fireline are defined. These can be found in any combination and are as follows:

1. Scratch line – hastily built, hit-and-miss line that attacks hot spots, but stops forward progress.
2. Wet line – line made by wetting fuels ahead of the fire by either ground or aerial application.
3. Black line – previously burned, or burning a strip with the express purpose of stopping the fire versus reinforcing other types of line.
4. Retardant line – line composed only of retardant and no other physical clearing which has been applied either from the air or the ground.
5. Mineral soil line – line built to mineral soil by hand crews or machines.
6. Vegetative clearing and modification – the enhancement of fireline through clearing, removal, limbing, or other modification to the cover by hand or mechanical processes.
7. Natural barriers – line made through use of rivers, lakes, rockslides, and other natural barriers.
8. Cultural barriers – line made with roads, railroads, power line rights-of-way, and other preexisting manmade barriers.

SUPPRESSION CAPABILITIES OR LINE PRODUCTION

To date, most fireline production data are based on point-to-point construction only. There is a wealth of qualitative production interpretation and outputs which are ranked high to low for rates of construction. This approach may be desirable from an operational application standpoint, but it is difficult, if not impossible, to compare, pool, or analyze such data. Many of the specific elements that can cause changes or affect rates of production are considered in a general sense, if at all. Limited ties, if any, are made with fire behavior characteristics, with the exception of spread rates.

Producing fireline at a rate that is fast enough to exceed the fire growth rate is only one of our concerns. We must also consider economics and conditional and site factors in the overall model, not just assume that the line is adequate and will hold. Fireline production must further be viewed in a total system context, covering everything from detection time through mopup, and effects of suppression action must be seen in terms of land management objectives. Fireline production information should also link with existing systems and models as completely as possible, such as National Fire-Danger Rating System (NFDRS), fire spread models, fuel models, etc.

Considering the background and evolution, as well as current needs and applications for fireline production information, a revised approach to the issue seems to be appropriate. The problem of developing a fire suppression production model is broad and complex. Such a task demands consideration of almost an infinite variety and combinations of items. In order to approach the task in a manner that will facilitate discussion, it has been segmented. The components are often interrelated, but the segments outlined should help in the discussion and understanding.

The process of fireline production is illustrated in figure 2. Four phases have been delineated—the management phase, the theoretical production phase, the application phase, and the evaluation phase. Under the management phase, policy, management goals, and objectives provide inputs and eventual decisions to take suppression action, as well as define the types and extent of such action. Once a decision is made to suppress the fire, the theoretical production phase is implemented. In this phase, the suppression resource options are reviewed and modified, as appropriate, and this theoretical information fed into the application phase. The application phase converts the theoretical production rates into actual production projections based on existing conditions. In the final evaluation phase, the tactics, along with the adjusted production rates, are used to determine costs, cost-benefits, or other effectiveness or evaluation information. Also, this last phase includes an evaluation of effects and probability of success. Depending on the constraints at the outset, the fire is either suppressed after the first time through, or else sufficient iterations through the system are made until all conditions are satisfied.

Management Phase

Application of the fireline production information can fit into three basic categories: (1) wildfire use, (2) prescribed fire use, and (3) use in simulation. Information can be used to address needs in both action (real-time) situations and planning through all levels of resolution and time horizons. The management phase includes all legal, organizational, and operational constraints or guidelines that affect the situation under consideration. Perhaps the most important consideration here is the management objectives. What is to be done with the resource and the consequences of action or nonaction are very important considerations. The effect of the suppression action itself, which is closely related to fireline production, is today often as important as many other considerations related to fire. Environmental concerns and consequences also play a major role in decision and allocation processes. This phase is really the key in subsequent action determination, including the selection of type, timing, and placement of one or more fireline production options.

Theoretical Production

The theoretical production phase encompasses all the fireline construction and suppression production resource options. In resource options, all types of personnel, equipment, and material used to produce fireline are considered. In this phase, theoretical rates are established. In addition, substitution possibilities are explored within or among production categories. For example, a TD-24 dozer might be directly substituted for a D-8 dozer similarly equipped. One 1,000-gallon pumper truck might be substituted for two 500-gallon pumper trucks, etc. Combination operations can also be developed using numerous combinations of both personnel and equipment to develop single production rates from multiple inputs. In this phase, the ultimate output is called a theoretical or potential output rate. This rate is unencumbered by any factors that might cause it to change. Change in rate is discussed in the next section.

Application Phase

The application phase is the phase in which the basic theoretical production rates are modified to meet an array of conditioning factors. The adjusted production rates are further modified by (1) the availability of production resources—if limited quantities or no specific resources are noted, it is not reasonable to consider them in determining rates; (2) the tactic, or type of attack and type of line to be constructed, as influenced by fuel, fire, and topographic constraints, is the final modifier to the system. The modified production rate value put out at this point is the value needed for each specific application.

Evaluation Phase

The manager can determine such items as cost per unit, cost-benefit, probabilities of success, strength of force requirements, and a myriad of other values. This final phase has been called the evaluation phase. The decision to either go to work on the fire or redefine the suppression strategy is made only after the projected results are compared with the management objectives.

FIRELINE PRODUCTION CONCEPTUAL MODEL

The general process flow diagram (fig. 2) can be expanded, providing additional detail. This detailed expansion can be considered a conceptual model for fireline production. Figure 3 illustrates the model, including the four phases and major components. More detailed explanation of some components will be developed in subsequent paragraphs. Numbers in parentheses within the diagram boxes are used to key the item to the text explanation.

Phases in this presentation of the model are similar to those discussed in the previous section. The only difference here is that the diagram orientation has changed. In the management phase, several decisions or conditions must be met before proceeding. First, the fire event begins the flow of action. This fire event can be a wildfire, a prescribed fire, or some form of simulated fire. Once the decision to suppress has been made, we can proceed through the model. The decision can even be "I think I want to suppress, but am not sure." In any case, by running through the model, one can assess the merit or relevance of a variety of information, which can contribute to the ultimate decision.

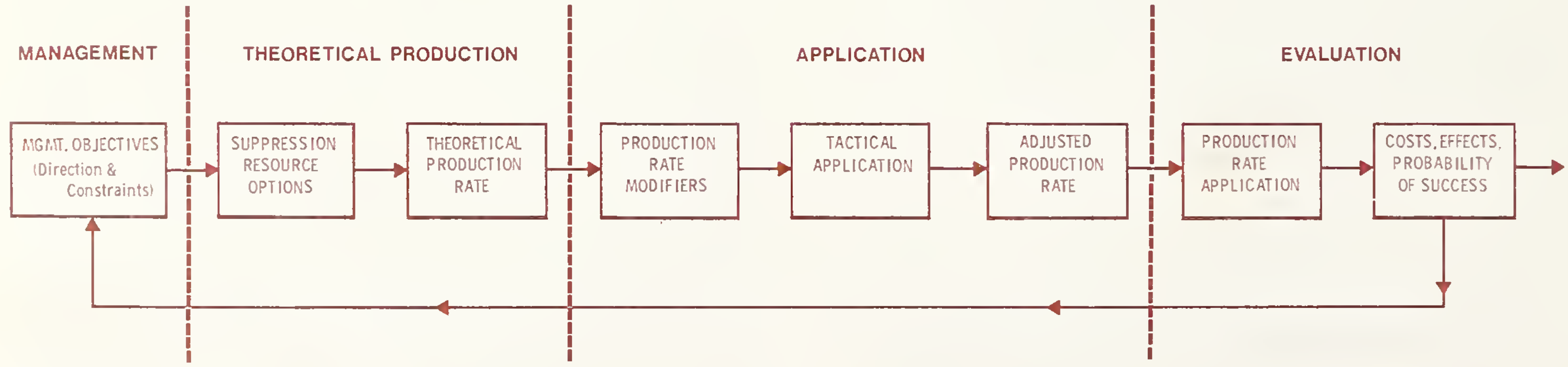

Figure 2.—General process flow for fireline production.

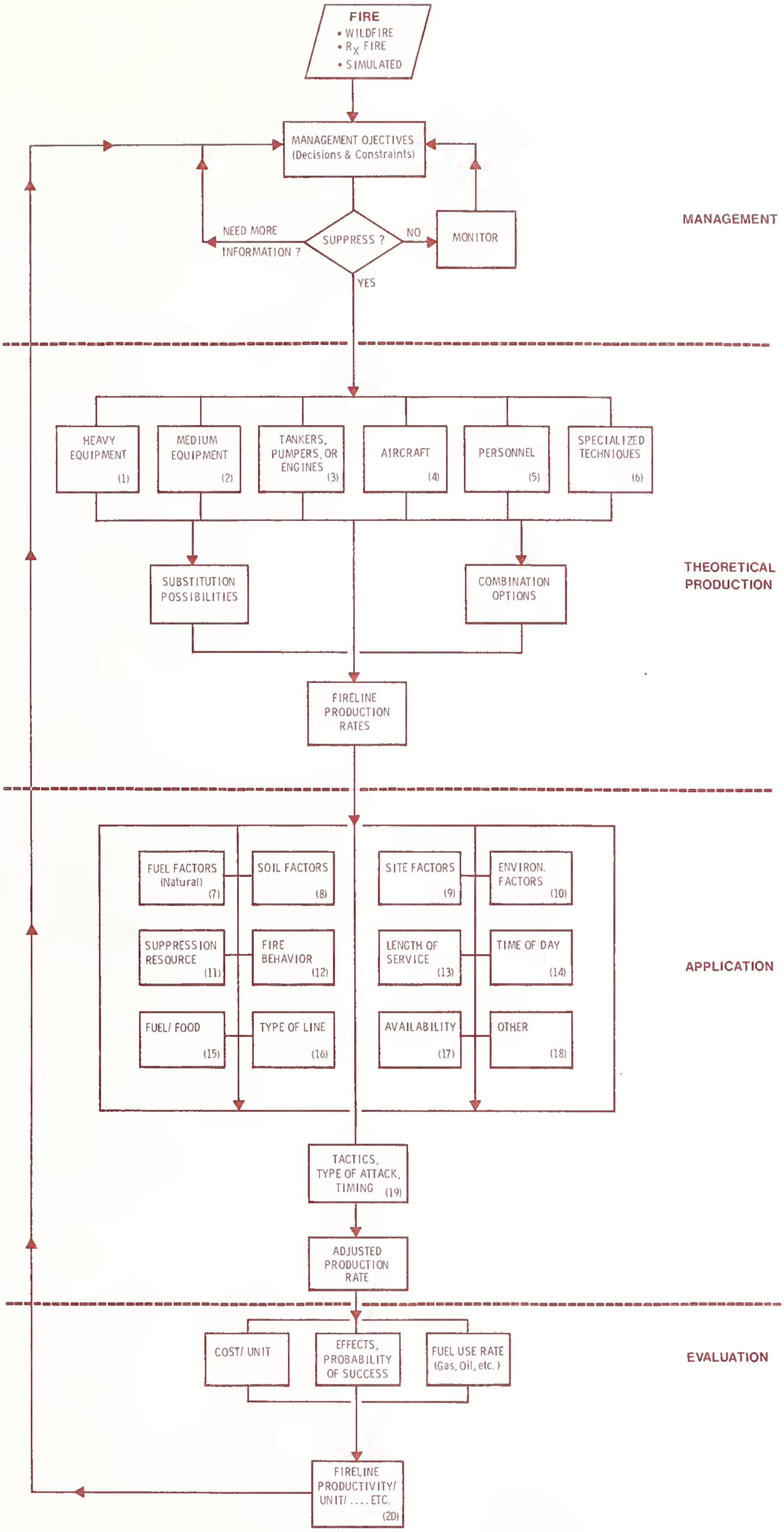

Figure 3.—Fireline production conceptual model.

In the theoretical production phase, we make first contact with the machines, personnel, or other devices that can be brought to bear in the construction of a fireline. In this model, (1) heavy equipment has been defined to include primarily dozers (tracked equipment with push blades) of the D–7 size class or larger, and (2) medium equipment has been defined to include D–4 through D–6 size dozers and fire plows and similar units. Water-hauling and water-handling equipment mounted on its own transportation (truck) is characterized by tankers, skidders, pumpers, or engines (3). This category includes equipment ranging from 100-gallon slip-on tank and pump units to 10,000-gallon units that are designed to haul, pump, and discharge water through hoses and nozzles. The aircraft category (4) includes all models of both fixed- and rotary-winged (helicopters) aircraft. Their applications may be both tactical and logistical.

Personnel (5) is perhaps one of the most complex categories of production resources. It includes all configurations of personnel forces assembled to suppress fires in some organized manner. Breakdowns within this group include, but are not limited to, numbers, age, training, types of crew, and experience. The possible combinations of utilizing personnel are large.

The final category of production resources—specialized techniques (6)—is, in essence, a catchall. This category provides a classification niche for anything not already covered. Production resources here are exemplified by the modified logging equipment, trenchers, and other equipment that does not fit into previously defined categories. Explosives, a promising technique in the Western States and Alaska, also fall into this category.

The numbers of boxes representing production resources certainly could be increased. The lists and specifications within each box could be extended. Grouping similar types of resources limits the diagram's complexity.

As pointed out earlier, most of the production resource options have a substitute that will produce a similar rate of production. In the case of heavy and medium equipment, one brand may be substituted for another with similar specifications, resulting in the same production potential. A helitack crew might be substituted for a smokejumper crew of similar size, etc. The important point is that specific production resources can be substituted for others if a substitute resource is available.

Another important option—combining resources—exists to develop similar production rates. Essentially, what this means is that for a vast array of equipment, pumpers, aircraft, personnel, and specialized techniques, combinations can be assembled to produce a similar rate of production. For example, if one D–8 breaks down, it might be replaced by a D–4 and a D–6 tractor, along with a saw crew, to give a comparable rate of fireline output. Again, many possible combinations will develop a required rate of production.

By using substitute possibilities, combined options, or basic production rates, we can determine what an unencumbered production rate or rates would be. An unencumbered or potential production rate is essentially a theoretical rate or optimum condition rate. Before it can provide useful information in an application sense, it must be tempered by a host of modifying factors. These modifying factors are both site- and situation-specific, which make them directly related to application directions.

The factors that modify the theoretical production rates at this point are of both a static and a dynamic nature. Figure 3 illustrates in the application phase those specific items or class of items that are felt to be most important in accounting for rate changes. In addition, these factors are also, for the most part, important in linking with other operational and conceptual models.

Fuel factors (7) for naturally occurring biomass in the field are important not only in respect to their direct effect on fire, but also in their direct effect on rates of production. Specific items such as types of material, quantity, spacing extent, and environmental conditions are all important considerations in modifying rates of production; for example, the numbers of logs of a certain size class per unit of line distance encountered affect the output rate. Other appropriate characteristics specific to fuel can similarly be considered.

The kind of material in which the line is being built may also play an important role in production modification. Soil factors (8) that can be involved include soil types (sandy, clay, loam, peat bog, etc.). The amount, size, and distribution of rocks are also important. If the soil is an organic type, the soil depth and moisture condition can be of critical importance.

Site factors (9) include slope steepness, exposure, and similar physiographical features affecting both production and fire behavior. On the other hand, environmental factors (10) include wind, temperature, precipitation, cover, and other similar factors of both long- and short-term that tend to condition the site and may directly influence personnel. Fire danger rating is often used as an integration of these individual elements.

Suppression resources (11) and availability (17) are closely related. The suppression resources used at this level include those that might be brought to bear on a specific situation. This would include types, sizes, numbers, etc., or the more specific information of what is actually within reach of the suppression organization. Availability and suitability of resources ultimately assist in the determination of use. Availability can be cast in terms ranging from "Is such a resource available at all?" to "Is the resource available for use within the specified time frame?"

How a fire behaves or is projected to behave is, perhaps, one of the most important considerations in determining production rates. The fire behavior information (12) indicates the size of the job ahead. Rate of spread indicates the rate at which line must be produced to contain and suppress a fire. Flame length and fireline intensity indicate whether the fireline is feasible or not, how wide the line must be, and how close to the fire personnel and equipment can be placed, if feasible. The amount of mopup required and potential effects are a function of fuel characteristics, residence time, and afterburning. Therefore, fire behavior is a very important modifying factor in production.

The length of time personnel or equipment have been in service (13) has both positive and negative effects on production. In the case of personnel, length of service can improve experience and efficiency. Alternately, if we consider in-service as time on a specific fire or shift, there is a direct relationship to fatigue, mental attitude, and related conditions that affect production output. Equipment, including operators, can be affected in a very parallel way. The older the equipment and the longer it has been used, the more prone it is to breakdown. Therefore, the administrative constraints of total life as well as shift time of equipment can be a tempering factor in output. Also, administrative and legal constraints on the use of personnel and equipment, maintenance, safety, etc., impact output.

Directly related to the service factor is time of day. At night, fireline production is much different than during the day (14). Heat, light, temperature, visibility, and humidity all affect personnel, equipment, fire behavior, and other factors in the production of fireline.

Fuel and food (15)—fuel for machines and food for personnel—are mandatory production considerations. Short supply of food or unappetizing food adversely affects personnel in the same way as bad fuel or no fuel influences equipment operations.

The type of line (16) to be built is an important influence on production. The requirement for line is a function of the management objective. The kind of line to be built is determined by a combination of all factors just discussed. Important factors not covered can be handled in the "other" category (18). The fire strategy, planned or implemented tactics, including the timing and type of attack (19), will temper as well as be tempered by all these modifying factors to finally arrive at an adjusted production rate.

Once an adjusted production rate is available, the number or numbers can be used in the evaluation phase. It is at this point that management information is put into a form for either the decision to go to work or to go back and try a different mix or approach to satisfy the objectives. The fireline rate productivity value (20) should, at this point, be expressed in terms of unit of line per cost, or time or resource saved, or any appropriate unit or units that allow the decision criteria to be evaluated and met.

SUMMARY

In planning, action, or research, the utilization of the conceptual fireline production model as outlined in the previous pages can enhance all efforts. First, the parts and their relationships are defined, allowing the linking with other operating models, such as fire behavior and fuel models, as well as simulation models under development or yet to be developed. Standardization of elements is also a key to future compatibility of components.

Perhaps most important will be the ability of managers to tailor production outputs to their specific conditions. Development of functional relationships through application of the model will facilitate all forms of calculations. This system for determining and applying fireline production information will improve planning and fire management through a more complete and common understanding of the processes involved.

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A conceptual model for fireline production is presented. The model provides a framework for the components of production and indicates logical linking points for other conceptual or operational models. The diagrams offer a system to enhance fire management and land management planning through an understanding of the fireline production components and process.

KEYWORDS: fireline production, fire management, conceptual model

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